Game Port Physics Introductory Experiments in Linear Dynamics

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The computer's ability to gather and analyze large amounts of data is of particular use in science. Any use of sophisticated equipment in a teaching laboratory however carries with it the danger of the 'Black Box Syndrome'; that is the student may lose sight of the laws under investigation and learn only how to manipulate the dials of the black box. The computer's ability to simulate experiments carries this threat one step further. A student who does too many simulated experiments may begin to believe that the reality of nature is in the perfect machine and not in the scatter of results he himself achieves in the laboratory.

In this series of experiments we attempt to avoid the black box syndrome by having the student write his own programs to obtain and manipulate the experimental data. For a similar reason we try, using a minimum of external logic, to make the interfacing as simple as possible.

Until recently the electronic complexity and expense of interfacing computers with the laboratory, together with the need to program in machine language, effectively precluded their use in introductory laboratories. However, there have been a number of courses developed which use single board computers (Rafert and Nicklin, 1982). These problems have been removed by the advent of the game port equipped 'home computer'. The game ports on these machines allow both analog and digital input. Equally important, these inputs are easy to read from BASIC, using either specific commands as with the Atari or simple 'peeks' as with the Apple (McInerney and Williams).

We require that students have a minimum competency in BASIC before they begin this course of experiments. We recognize that developing software is not an easy task so we have attempted to structure the experiments such that each succeeding program is built on one that has come before. Similarly, students do not attempt to present their results by way of a graphics display on the video screen. Instead students are encouraged to plot graphs as part of their laboratory report.

Graphs are very important when working with computers as they offer a good way of presenting the large amounts of data gathered by the machine. The scatter of points on the graph also gives an idea as to the experimental error. It is, of course, possible to use the computer for a more sophisticated error analysis. Unless the students themselves write the error analysis programs, however, we do not believe they should be used in introductory laboratories.

We have been working with the Atari 800 computer and the examples to be quoted will use the Atari version of BASIC. In particular we use the game port access commands of the Atari. Nevertheless, the ideas contained in this paper are simple to transfer to other game-port equipped microcomputers.

Course Outline

Introduction

The student begins by familiarizing himself with the game port inputs. He learns the access functions for the analog paddle inputs and the digital joystick and trigger inputs. Simple program loops are written to observe how the access functions vary with variation of input to the sensors. For example, A 1 megohm potentiometer may be connected across the paddle and +5V of the game port and varied while the program: 10 PRINT PADDLE (0) : 20 GOTO 10: is run. The switching effect of a simple photogate is observed by connecting it across trigger and GND and running the program: 10 PRINT STRIG(0) :20 GOTO 10. The screen will show A 0 when the light of the photogate is on and A 1 when the light is off.

The Interval Timer

Dynamics experiments require the measurement of speed which in turn requires a time measurement. Experimentally this time measurement is the interval during which the light across the photogates is blocked. The Atari, along with other common computers, has a real time clock within it. This clock, however, increments in sixtieths of a second and thus is not accurate enough to act as an interval timer for our experiments. We have written a software timer that is accurate to about one tenth of a millisecond.

The timer, which is a machine language routine called from BASIC, works in the following manner. The microprocessor checks the trigger pin of the game port until it sees the 0 change to 1. Once this change occurs, which indicates that the photogate is blocked, the microprocessor increments a memory location and looks at the trigger pin again. Counting and checking continues in this manner until A 0 is found in the trigger location (photogate unblocked) whereupon control is returned to the BASIC program.

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The interval timer returns a count distributed across three memory locations M_1, M_2 and M_3. The total count is derived
from these numbers by the formula:

$$\text{TOTAL COUNT} = (M_1)*256*256 + (M_2)*256 + (M_3)$$

Note that (M_1) indicates the contents of memory location M_1.

This formula derives from the fact that each memory location cannot hold a number greater than 255 (11111111 in binary).

Timers based on simple counting, such as the one described
here, have a number of drawbacks. Microprocessor interrupts, which occur frequently in order to update the screen and perform a number of housekeeping chores, stop the counter for an indeterminate time. A typical chore which we find too useful to eliminate is the regular incrementing of the real time clock. We have managed to eliminate most interrupts while the counter is working, inlcuding the screen, with the result that the screen is blanked out by the counter. The blank screen is not a drawback as the time intervals measured are small.

Our timer is not the only method of achieving a soft-ware clock on the Atari; other methods exist and are used by Dr. Laws and Associates who are also working on introductory experiments with the Atari (Laws, 1983).

The student practices using the interval timer with the photogate and observes how the numbers (M_1), (M_2) and (M_3) change. With a little prompting he/she discovers the formula for deriving the total count from (M_1), (M_2) and (M_3). The calibration is carried out by the student using a stop watch to measure the time that the photogate is blocked by a piece of card. These calculations are drawn together in a program TIME which displays in seconds the interval that the photogate is blocked. TIME is stored on disk.

Experiments with Speed

It is a simple matter to modify the TIME program to a SPEED program which measures the average speed of an object passing through the photogate. This SPEED program is also stored on disk.

Armed with SPEED, the student can perform a number of interesting experiments on the air track. To get the feel of things, he sets the aircart, fitted with springs at both ends, running back and forth through a photogate where SPEED takes the aircart's average speed. It is observed that the speed gradually decreases. A discussion is encouraged as to whether the loss in speed is due to air friction or to inelastic collisions with the end of the track.

The loss of speed can be further investigated by determining the coefficient of restitution for collision between the spring equipped aircarts and the end of the airtrack, and by determining the friciton on the air track. If the photogates are connected across the airtrack as shown in Figure 1, the data for both the friction and the coefficient of restitution may be taken at the same time. Simply, the aircart is set moving backward and forward on the airtrack and the speed each time the cart moves past one of the gates recorded. These speeds are stored in a file V(I).

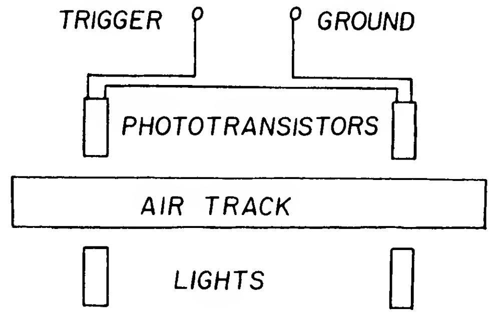

Figure 1. Arrangement of photogates in series for air track experiments; 'Trigger' and 'Ground' are game port connections (McInerney and Williams 1982).

After allowing the aircart to slow down almost to a standstill, the frictional force (FF) for various trips down the track may be found from:

$$FF = M*[V(2*I-3)*V(2*I-3) - V(2*I)V(2*I)]/2S$$

Where M is the mass of the aircart and S the distance from the photogate to the far end of the track and back. It is generally accepted that air resistance varies as the square of the speed; the dependence of FF on the average speed $[V(2*I-3) - V(2*I)]/2$ squared is shown in Figure 2. This

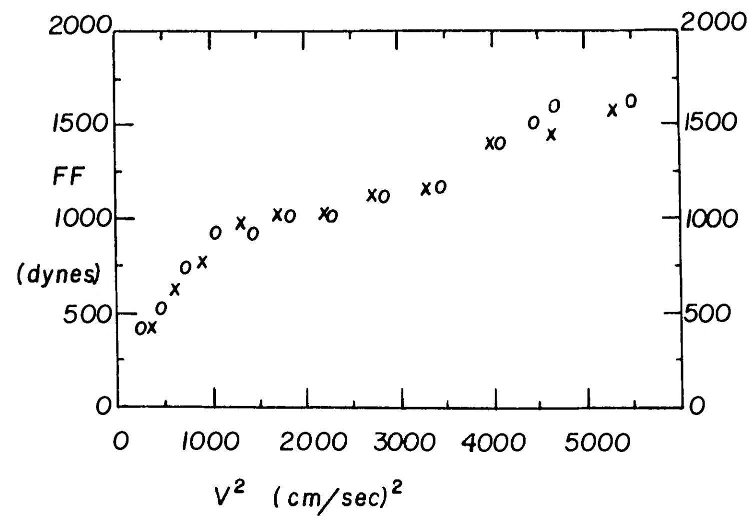

Figure 2. Friction (FF) on the air track as a function of the square of the speed; 0 and X refer to separate experimental runs.

dependence is a straight line for most speeds; the anomalous behavior for low speeds may be due to irregularities in the airtrack.

We use V(2*I-3) and S in our expression for FF rather than V(2*I-1) and the distance between the photogates because the former expression uses speeds taken at the same photogate. The error introduced by the collision at the end of the track is rather less than that due to the different response times of the two photogates.

The coefficient of restitution may be found for different initial speeds V(I) from the ratio V(I + 1)/V(I). The student plots values of the coefficient against incident speed and looks for any systematic change. We have found, as shown in Figure 3, that the coefficient tends to decrease for slow speeds. The student is encouraged to see any deviation of the coefficient from a constant value as a change in the energy absorbing mechanisms of the collision. The decrease of the coefficient at low speeds may be due to isothermal rather than adiabatic compression of the aircart spring.

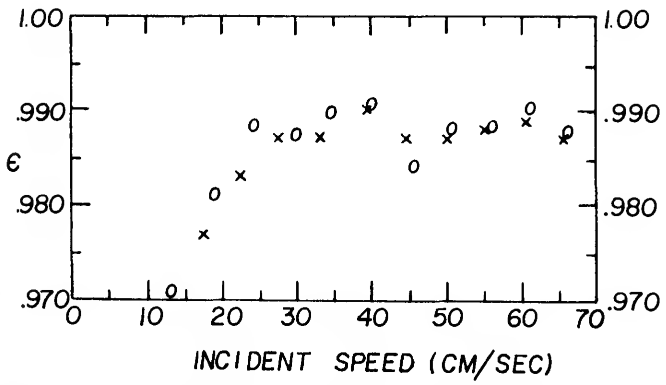

Figure 3. Coefficient of restitution (E) of air cart spring against the end of the air track as a function of incident speed; 0 and X refer to separate experimental runs.

With the two photogates in position the student goes on to test the conservation of linear momentum in a sticking collision in which one aircraft is initially stationary. It is a relatively simple matter for the student to modify SPEED into MOMENTUM; a program which returns the initial and final speeds and the initial and final momenta. In presenting the report for this experiment, a graph of initial against final speed for a variety of initial speeds is required. The conservation of momentum is tested by comparing the slope of this graph, which should be a straight line, with the theoretical prediction, typically, agreement with theory is within 2 percent.

The Real Time Clock and Acceleration

The Atari, together with other home computers, has a real time clock. This clock allows us to find the speed of the aircart at a particular time and hence to find the acceleration. The student modifies SPEED to SPEEDT, a program which looks at the real time clock immediately after using the interval timer. Using SPEEDT it is not difficult to write NEWTON2 which measures the speed and time of an aircart at two ends of the airtrack as the cart is being accelerated down the track by a known force. With this information NEWTON2 calculates the acceleration and compares it with that predicted by Newton's second law. Once again the presentation of these results is in graphical form. The slope of the line being compared with the predictions of Newton's Law.

Acceleration of Gravity

To compare the classic cycle of introductory linear dynamics experiments, the student performs a simple experiment to determine the acceleration of gravity.

Previous experiments have not depended on the accuracy of the timer calibration as they were concerned only with ratios of speeds. Determining the acceleration of gravity accurately, however, does require an accurate timer calibration.

Measurement of G is achieved by dropped a C-shaped piece of metal (See Figure 4) through the photogate (Mosca, 1983). T1 and T2 are the times for the top and bottom arms to pass through. The acceleration of gravity, G, is found from various distances described in Figure 4. The time measurements and calculations are carried out by GRAVITY. GRAVITY is a simple modification of TIME.

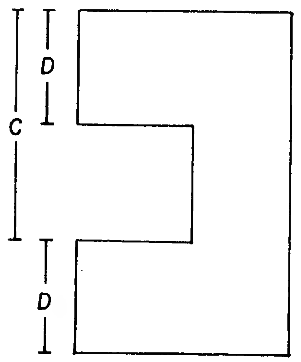

Figure 4. C shaped piece of metal used in the determination of the acceleration of gravity (g) from the relation:

$$g = 2\{2C - [4c^2 - D^2(T1^2 - T2^2)^2/T1^2T2^2]^{1/2}\}/(T1^2 - T2^2)$$

The value of G which we obtain in this experiment varies from trial to trial because of difficulties with the experimental equipment and with dropping the C-shape vertically through the photogate. The photogate is not perfectly collimated so that the size of the arms of the C as SEEN by the photogate is slightly less than the actual size. At the same time if the C-shape is not dropped properly, it will twist and the arms will not be horizontal as they pass through the photogate. In this case the arms will appear longer than they really are. The value of G obtained by this experiment is very sensitive to the apparent size of the arms; hence there is a scatter of results.

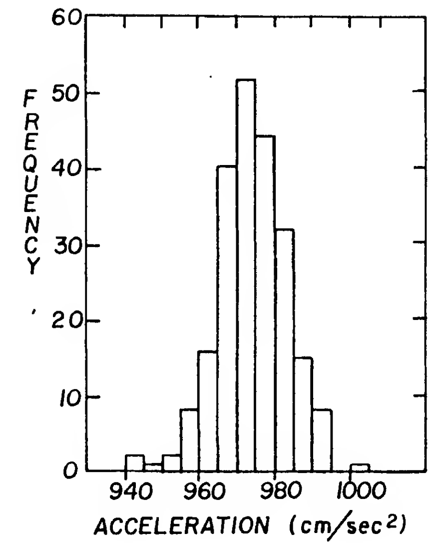

Figure 5. Bar chart of the results of 222 measurements of the acceleration of gravity (g) taken within 15 minutes; average value of g is 973.8 cm sec.$^{-2}$.

This scatter of results may be used to advantage as an introduction to statistical methods of dealing with experimental error. In this usage the computer comes into its own as the student can quickly take three hundred readings and plot them in a bar chart as shown in Figure 5. The distribution of results is as would be expected from random error.

Conclusion

It is clear from this series of introductory experiments that the computer offers the student an opportunity to observe trends he might otherwise miss. The dependence of air track friction on the square of the cart speed is a good example.

These experiments have been successfully tested on a number of freshman physics and engineering students and have been enthusiastically received. The major strength of our approach, we feel, is its emphasis on the essential physics of the experiments while affording the student useful experience of automatic data collection. □

References

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